PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G05B 17/02

A1

(11) International Publication Number: WO 99/14642

(43) International Publication Date: 25 March 1999 (25.03.99)

(21) International Application Number: PCT/GB98/02717

(22) International Filing Date: 11 September 1998 (11.09.98)

(30) Priority Data:
97307113.7 12 September 1997 (12.09.97) EP

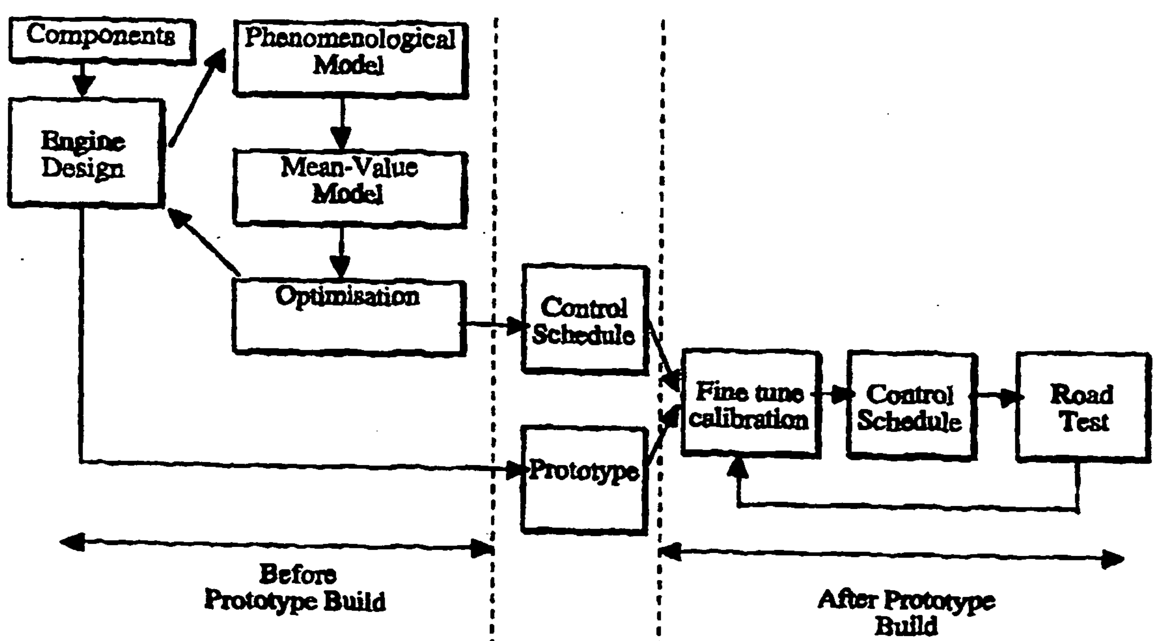
(71) Applicant *(for all designated States except US)*: CAMBRIDGE CONSULTANTS LIMITED [GB/GB]; Science Park, Milton Road, Cambridge CB4 0DW (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: MASON, Julian, David [GB/GB]; Cambridge Consultants Limited, Science Park, Milton Road, Cambridge CB4 0DW (GB). STOBART, Richard, Keith [GB/GB]; Cambridge Consultants Limited, Science Park, Milton Road, Cambridge CB4 0DW (GB).

(81) Designated States: JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: MACHINE CONTROLLER CALIBRATION PROCESS



(57) Abstract

A method for deriving control parameters for a machine controller which involves using a mean–value model of the machine in a computer optimisation scheme to derive the control parameters. The mean–value model is derived from a phenomenological model of the machine.

AN

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

Machine Controller Calibration Process

Field of the invention

The present invention relates to methods and apparati for calibrating machine controllers. In particular, the present invention relates to a method for calibrating a controller which controls an internal combustion (IC) engine.

Background art

Machine controllers which work on the basis of multi-dimensional look-up tables are known in the art. For example, US-A-4,489,689 discloses such a controller.

Such a known controller may have look-up tables in which each dimension of a look-up table corresponds to a particular sensor sensing some functional state of the machine, such that each particular combination of sensor values corresponds to a unique cell in the table. The cells of these look-up tables contain appropriate values for the control inputs to the actuators controlling the machine, depending on the steady state condition of the machine as indicated by the sensor values. Additional compensation may be added to the actuator values when the machine is in a transient condition.

Before such look-up table controllers can be used to control a particular machine, the controller must be calibrated, i.e. the entries in the look-up table must be completed.

By way of example for a prior art machine design process, Fig. 1 shows a schematic depiction of a typical prior art design process for the design and prototyping of a new engine.

A new machine design is typically built up starting from a basis of a combination of readily bespoke parts, assemblies from third parties, components from previous models of the machine and new parts. A design is drawn up and the designers may build phenomenological models of the intended design in order to allow them to predict performance of the machine. It is to be noted

that although such phenomenological models are available, many designers do not use them, preferring to use more traditional approaches.

If they are used, such phenomenological models are generally based on the physical design characteristics of the machine being designed. Software packages exist which help designers to build such phenomenological models such as the CPower™ Matlab toolkit produced by Cambridge Consultants Ltd., Cambridge, U.K. Although extremely accurate (the best have resolutions down to sub-cycle periods), these models require long calculation times.

Once the designers have designed the machine in question, a prototype is manufactured according to the design. The look-up tables of the machine controller are subsequently filled in by a manual calibration process involving skilled operators who run the machine and manually adjust actuators which control the machine in order to achieve the desired performance. In a similar fashion, cell values for the look-up tables are also arrived at for adapted tables for transient machine conditions and for adapted tables which allow, for example, for ageing effects or for particular environment effects, such as for meeting the various different emissions regulations of different countries in the case of IC engines. For example, for a car engine, the engine may be placed on a dynamometer test bed and the skilled operating staff would adjust the various actuators (choke, throttle, ignition advance etc.) and record the appropriate values for use in the look-up table of the engine controller.

The conclusion drawn by the skilled machine calibrators is often that the particular prototype is not suitable and this information is then passed back to the designers who rework the design and the original prototype is then reworked or a further prototype is built. This loop is continued until an acceptable machine in combination with an acceptable controller are produced. The prototype machine is then further tested in the environment in which it is to be used (e.g. for car engine

designs, the car is road tested) and again, this often leads to iterations through the calibration process.

The prior art machine controller calibration process is very time-consuming, labour-intensive and entails the manufacture and calibration of a plurality of prototype machines. The people involved in this time-consuming process are highly skilled and thus expensive. For example, in the car industry it is said that the time and costs involved in the engine controller calibration process is one of the major factors limiting the introduction of new models of cars. The length of the calibration process also involves opportunity cost and has implications for market share associated with any delays at this stage in the development cycle.

The situation is compounded by ever more stringent machine performance regulations, such as pollution regulations for IC engines. In order to meet these more stringent regulations, while still providing the desired functionality, manufacturers generally add both extra sensors to more closely monitor machine condition and extra actuators to effect better control (e.g. for an IC engine: exhaust gas recirculators, variable geometry turbochargers etc.). Since the length of the calibration process is roughly proportional to the square of the number of control variables (i.e. sensors plus actuators), such additions dramatically increase the amount of calibration work needed and the time required to complete the prototyping process.

Indeed, as the regulations become more strict and the machine control systems become more complex, manual calibration may cease to be a feasible procedure. The present state of the art does not offer solutions to this future problem.

In the prior art, the most-used method for reducing the length of the calibration process is to base machine design as closely as possible on previously successful designs and to initially fill the relevant look-up tables with values arrived at heuristically based on the values used in the look-up tables of previous designs.

Furthermore, the accuracy of look-up-table-based control systems has an upper bound imposed by the use of the look-up tables. Although steady-state conditions are accurately represented by these standard controllers, the transient compensation schemes used in conjunction with the look-up tables are far more approximate. However, machines tend to be used for large proportions of their operating time in transient states - for example, car engines used in urban driving conditions. As the test cycles used for measuring machine performance in order to test for the meeting of various regulations (e.g. emissions test cycles) will inevitably change to reflect the use of a machine in transient states, contemporary controllers will no longer provide accurate enough control to meet the relevant regulations.

It is the general aim of the present invention to provide a method of machine controller calibration which is quicker than prior art methods and which involves less likelihood of having to rework or rebuild machine prototypes.

In particular, it is an aim of the present invention to provide a machine controller calibration process which enables a model of the machine to be constructed from which control parameters for the machine controller may be derived without the need for building a physical machine prototype.

It is also the aim of the present invention to provide a machine controller calibration process which enables machine designers to use more complex controller architectures such as, for example, optimal, adaptive, predictive or neuro/fuzzy controllers. Thus the present invention enables the development of better machine controllers.

Summary of the Invention

The present invention provides a machine controller calibration process for calibrating a machine controller comprising the steps of:

i) constructing a phenomenological model of the machine;

ii) constructing a non-parametric model of mean-value machine characteristics derived from the phenomenological model;

iii) using the non-parametric model for deriving control parameters for the machine controller.

whereby, a prototype controller may be derived without the need for manufacturing a physical machine prototype.

In another aspect, the present invention provides a method of producing a non-parametric model of a machine which method involves the use of a neural network acting on the mean-value machine characteristics derived from a phenomenological model of the machine.

In a further aspect, the present invention provides a method for deriving control parameters for a machine controller which involves using a mean-value model of the machine, which mean-value model has been derived from a phenomenological model of the machine, in a computer optimisation scheme to derive the control parameters.

In a further aspect, the present invention provides a method of automating a machine controller calibration process which involves using a mean-value model of the machine, which mean-value model has been derived from a phenomenological model of the machine, in a computer optimisation scheme to derive the control parameters of the machine controller.

The calibration method of the present invention allows machine manufacturers to meet, for instance, short-term emission requirements with reasonable calibration times, in use in conjunction with standard, look-up-table-based control systems. It also enables the simulation of the machine under transient conditions and thus enables machine designers to use the control parameters derived from the model to form the basis for a more advanced controller, such as for an optimal, adaptive, predictive or neuro/fuzzy controller.

Essentially the present invention uses two models to represent the machine - one faster and one slower. This approach means

that, whilst the faster non-parametric model does not contatin as much detail as the phenomenological model, it allows a very substantial speeding up of processing and can therefore be used in calibrating a machine controller or designing some form of optimal controller or the like in real time.

Since the invention allows the callibration of a machine without the need for building a machine prototype, the invention allows substantial cost and time savings to a machine designer/producer.

Further aspects, advantages and objectives of the invention will become apparent from a consideration of the drawings and the ensuing description.

Brief Description of the Drawings

Fig. 1: A schematic drawing of a prior art engine design process;

Fig. 2: A schematic drawing of a engine design process incorporating the calibration method of the present invention.

Detailed Description

By way of example for a prior art machine design process, Figure 1 depicts a typical prior art engine design process as described above.

By way of example for a machine design process using the calibration method of the present invention, Figure 2 depicts a typical engine design process using the calibration method of the present invention.

The major differences between the design processes of figures 1 and 2 are that:

i) the point at which the first physical prototype is built is much later in the design process of figure 2; and

ii) the building of the physical prototype is not in an iterative loop in the design process of figure 2, whilst it is in an iterative loop in the design process of figure 1.

This is achieved by using a phenomenological model of the engine to enable simulation in software, allowing a mean-value model to be constructed using, for example, a neural network (such as multi-layer perceptrons, Cyberko networks or radial basis function networks). The mean-value model is then fast enough to use in a computer optimisation scheme, thus enabling the semi-automation of the calibration process. The constructed mean-value model may advantageously be a non-linear model.

Under this scheme, when the first prototype is constructed, the calibration engineer will be provided with a control strategy which will then merely need fine-tuning in order to compensate for modelling inaccuracies. The time on the test-bed is thus drastically reduced and both time and money are freed up for use on something else.

It is to be noted that a machine controller may control only a particular part of a machine and not the whole machine. Clearly, the current invention is also meant for use in such circumstances - a 'machine controller' is intended to be interpreted as a controller of a machine or of some sub-system thereof. Examples of such sub-system controllers might be for controlling exhaust gas recirculation or for controlling a variable geometry turbocharger or for controlling electronic fuel injection etc.

Once the inventive concept of this invention is understood, the person skilled in the art would, without the use of any inventive skill, think of alternatives to the use of neural networks for constructing the non-parametric model. For example, cubic B-splines, ridge function approximators or even polynomial techniques are also appropriate for use in constructing the non-parametric model.

Claims

1. A machine controller calibration process for calibrating a machine controller comprising the steps of:

   i) constructing a phenomenological model of the machine;

   ii) constructing a non-parametric model of mean-value machine characteristics derived from the phenomenological model;

   iii) using the non-parametric model for deriving control parameters for the machine controller.

   whereby, a prototype controller may be derived without the need for manufacturing a physical machine prototype.

2. A machine controller calibration process for calibrating a machine controller according to claim 1 wherein a neural network is used to construct the non-parametric model of mean-value machine characteristics derived from the phenomenological model.

3. A method of producing a non-parametric model of a machine which method involves the use of a neural network acting on the mean-value machine characteristics derived from a phenomenological model of the machine.

4. A method for deriving control parameters for a machine controller which involves using a mean-value model of the machine, which mean-value model has been derived from a phenomenological model of the machine, in a computer optimisation scheme to derive the control parameters.

5. A method of automating a machine controller calibration process which involves using a mean-value model of the machine, which mean-value model has been derived from a phenomenological model of the machine, in a computer optimisation scheme to derive the control parameters of the machine controller.

6. The use of a method according to any of the preceding claims in the creation of an optimal, adaptive, predictive or neuro/fuzzy machine controller.

International Application No
PCT/GB 98/02717

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	SUNG HOON JUNG ET AL: "EVENT-BASED INTELLIGENT CONTROL OF SATURATED CHEMICAL PLANT USING ENDOMORPHIC NEURAL NETWORK MODEL" PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON INTELLIGENT CONTROL, COLUMBUS, AUG. 16 - 18, 1994,16 August 1994, pages 279-284, XP000549590 INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS see the whole document	1,2
P,A	WO 97 42553 A (PAVILION TECH INC) 13 November 1997 see page 10, line 1 - page 18, line 19	1

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 98/02717

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9742553 A	13-11-1997	AU 3132197 A	26-11-1997